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Biofuels, sustainability and the transport sector in Lithuania

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ABSTRACT

This review paper sets the stage for a look at the Lithuanian (hereinafter LT) transport sector and its transition towards sustainable mobility through the use of biofuels and implementation of the necessary policies to deliver the renewable energy targets.

The assessment begins with a brief and reasonably balanced situational analysis of the transport subsectors—road (including ex-fleet vehicle market), off-road, railway, marine, and air—in Lithuania, and their direct relations to the biofuel sector. The paper also aims to examine the dynamics of GHG emissions (N_2O, CH_4, CO_2), air and soil pollution (NO_2, SO_2, NMWOC, NH_3, PM, CO, heavy metals), and related indicators in the whole LT transport sector during the economic transition period (1990–1995), economy growth period (1996–2007) and the first-world debt crisis period (2007–2010).

The national biofuels industry has seen plenty of ups and downs over the past decade but have generally good growth prospects. The study found that the CO_2 emission is growing recently in Lithuania and this growth could be attributed to almost all transport subsectors. One of the main problems responsible for this situation is the patchy nature of the regulation (there is no governmental decision indicated on setting of national fuel economy/GHG standard), from which most other problems arise.

Transport activity has been a key facilitator and driver of economic prosperity in Lithuania and it is likely to continue to grow. It can produce both positive and negative effects on the environment and the quality of life depending on measures at all levels to promote its sustainable development.

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1. Introduction

In 2009, the scientific sub-community composed of 3146 earth scientists around the world who study and publish on climate science unanimously agreed that human-caused global warming and climate change are real and that human activity is significantly associated with global temperature change [1]. The main sources of air pollution worldwide are the industries and energy plants, also called stationary sources [2–4] coupled with mobile sources such as those in the transport sector [3–8]. The industrial and transport sectors involved in the production, sale and consumption of energy are presently confronted with deterioration of the environment through depletion of fossil fuel resources [9]. The search for alternative fuels, which promise a harmonious correlation with sustainable development, energy conservation, efficiency and environmental preservation, has become highly pronounced in the present context [10]. That is to say, moving towards 100% renewables in the energy system is a challenge for both the power and transport systems [11]. There are many debates that the gains in ecological efficiency and energy efficiency in relation to biofuels are relatively low while significant efficiency increases can only be expected when developing a transportation system based on electricity. It was established that electric vehicles contribute as much as 53% fewer "cradle-to-grave" (lifecycle) emissions than conventional fuel-powered vehicles, even factoring in such elements as the lithium that goes into electric vehicle battery bank. However, the future of the electric vehicle market is not yet fully defined due to competition from conventional internal combustion engine-powered vehicles that are currently more attractive due to their lower initial investment costs and continental wide infrastructure for refueling and other auxiliaries. Worldwide projections on the vehicle park are conflicting due to a number of assumptions including growth in population, vehicle lifetimes, technology developments and economic growth. Thus, electric mobility will not be further discussed in this paper.

Transportation plays an extremely important role in the socio-economic development of the greater number of all 195 independent countries [12] in the world in general and Lithuania in particular [13]. The modes of LT motorized transport are land transport, which includes road and off-road transport, rail, aviation and ship transport (see Fig. 1). Sector represents 2.5% of the total LT employment (see Fig. 1), thus being an obligatory component of the economy [13] and plays a major role in relation between different locations.

With a few exceptions, all modes of transport emit quantities of chemical substances from the combustion of liquid fossil fuels [7]. Most motorized means of transport at present therefore emit similar hazardous compounds into the atmosphere and induce chemical reactions, although the relative abundance of these pollutants varies depending on the fuel type, combustion completeness and exhaust after-treatment. Typically, dispersion of air pollutants get into the ambient air from: (i) vehicle exhaust removal system (65% of all the transport-related pollutants), (ii) crankcase ventilation system (20%), and (iii) hydrocarbon volatilization from a carburetor and fuel pump (15%) [14,15]. The higher energy efficiency of the fuel use leads to reduced air emissions and upstream energy use [16]. Despite automobile manufacturers' efforts to improve performance, the average consumption across the petrol-powered car fleet during the period 1985–1990 decreased only by 2% or from 0.096 l/km to 0.094 l/km. Car diesel consumption also reduced slightly from 0.084 l/km to 0.076 l/km or by 9.5% [7]. This situation has, of course, radically changed from that in the 1990s with the widespread introduction of gasoline direct injection and new diesel technologies. But the potential of traditional IC engine technologies development, alone, to reduce pollutant emissions may, however, be limited by the relatively small contribution of fuel savings to overall annual growth in transportation energy demand. Various actions are required to slow, stop and reverse the trend in GHG gas emissions. Lumbreras et al. (2008) [17] stated that with regard to CO_2

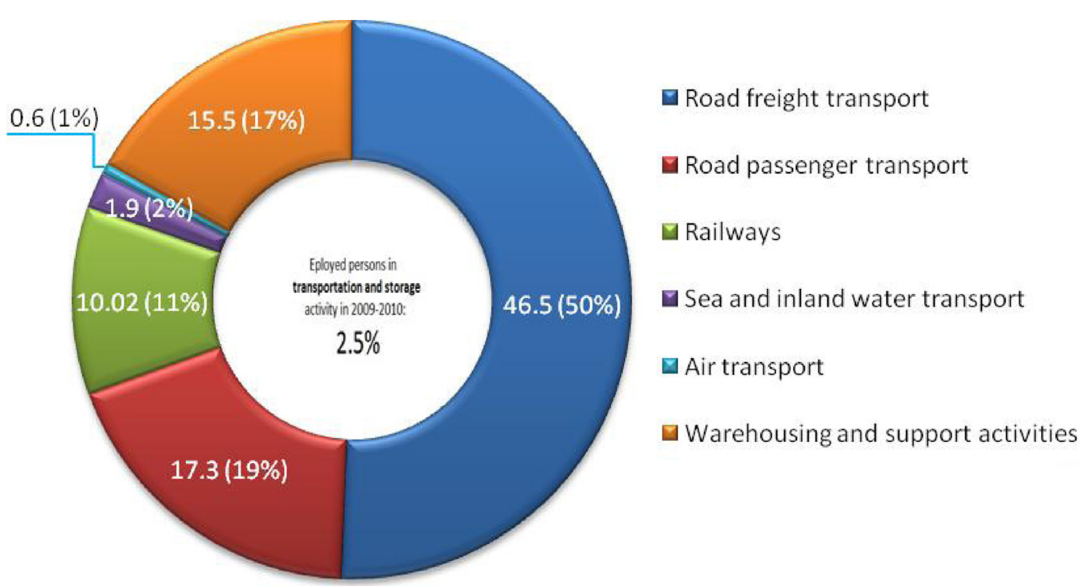


Fig. 1. Transport sector by mode in Lithuania in 2010.

emissions, decrease in mobility and use of biofuels are the most effective measures for emissions reduction. These current alternative transportation fuels can be termed as bioethanol and biodiesel. They must be economically competitive, easily available, environmentally acceptable, and technically feasible [18,19].Transportation biofuels are lumped into first- (1G), second- (2G) and third-generational (3G) categories and their use may improve the emissions levels of some pollutants and deteriorate others. Terminology regarding 1G, 2G and 3G biofuels is in popular usage, but it has no legal or regulatory meaning. 1G biofuels can offer some CO_2 benefits and can help improve domestic energy security; however, concerns exist about the sourcing of feedstocks, including the impact it may have on biodiversity and land use and competition with food crops [20]. Most transportation biofuels in use today are classified as 1G. They are also characterized by its ability to be blended with fossil fuels [4,20–27], combusted in existing IC engines, and distributed through existing infrastructure [20]. The term 2G can refer to biofuels produced either from advanced, non-food feedstocks or via advanced processing technology (or both) [20,21]. The production of 2G and 3G biofuels is non-commercial at this time, although pilot and demonstration facilities are being developed [21].

Scientists, decision-makers, members of civil society and business representatives are pushing the development of transportation biofuels for environmental and economic reasons. Some see biofuels as a substitute for highly priced petroleum, in order to ease the burden on consumers, to diversify the sources of energy supplies or to reduce escalating trade deficits [28]. Some have focused on biofuels as a way to extend available energy in the context of increasing LT demand for transportation fuels. Others target biofuels as a substitute for more carbon-intensive energy. Still others see biofuels as an economic opportunity [28]. In sum, all these actions are called “sustainable development” (the term emerged from the 1987 Brundtland report of the United Nations [29]).

In cases from different areas of sustainable development, there are many possible technological and legislative pathways that could not be singled out or quantified in great detail. Some of the particular pathways may lead to better environmental performance whereas some would entail worse performances [16]. Sustainable development concerns a process of change and is heavily reliant upon local contexts, needs and interests [30]. According to this conception, the review paper sets the stage for a look at the Lithuanian transport sector and its transition towards sustainable mobility through the use of biofuels.

2. Description of the Lithuanian transport sector

2.1. Road transport subsector—situational analysis

2.1.1. Road density, transport means and air pollution emissions

LT has a fairly well-developed and dense road network (1.26 km/km^2). There are 25.3 km of roads per 1000 inhabitants in LT and ~1103 km of surfaced roads per 1000 km^2 of the country's territory [13]. In December 2010, the length of roads amounted to 82,131 km; 87.7% (72,048 km) of them are paved roads. This is an increase of nearly 6.6 thousand kilometers (~8.0%) over the ten years from 2000. Local roads accounted for 74.1% of the total road length, with motorways (309 km) and ‘E’ roads (1666 km) accounting for 0.38% and 2.03%, respectively. Despite accounting for only 2.41% of the road length in 2010, major roads (motorways and ‘E’ roads) constitute the greater part of the road traffic [13,31,32].

In Lithuania 88.6% of all motorized road transport vehicles are cars (including ex-fleet vehicles—see Chapter 2.1.2.), 7.1% are freight vehicles, 1.6 are motorcycles, 0.8% are buses and 2% are others (Fig. 2). The LT road transport millage for each separate category in 2010 can be summarized as follows: passenger cars—7,502,454,100 km, heavy duty vehicles—1,887,711,951 km, light duty vehicles—1,566,991,000 km, buses—752,344,000 km, mopeds–10,176,919 km and motorcycles—5,632,879 km [31–34].

Road transportation is the most important emission source in the Lithuanian transport sector. This sector includes all transportation types of vehicles on roads (Table 1). The source category does not cover farm and forest tractors, construction, industrial and military vehicles driving occasionally on the roads, because they are labeled as off-road transport (Chapter 2.2).

As seen in Fig. 3, the lowest NO_2, NH_3, polycyclic aromatic hydrocarbons (PAHs), $PM_{2.5}$, PM_{10} and total suspended particle (TSP) emission levels in the road transportation was achieved in the period of major economic instability (1990–1994) in LT. Between 1990 and 2010, SO_X emissions from road transport decreased by 99% from 5.61 Gg to 0.02 Gg and increased by 7% from 2009 to 2010 [34]. This increase is primarily caused by

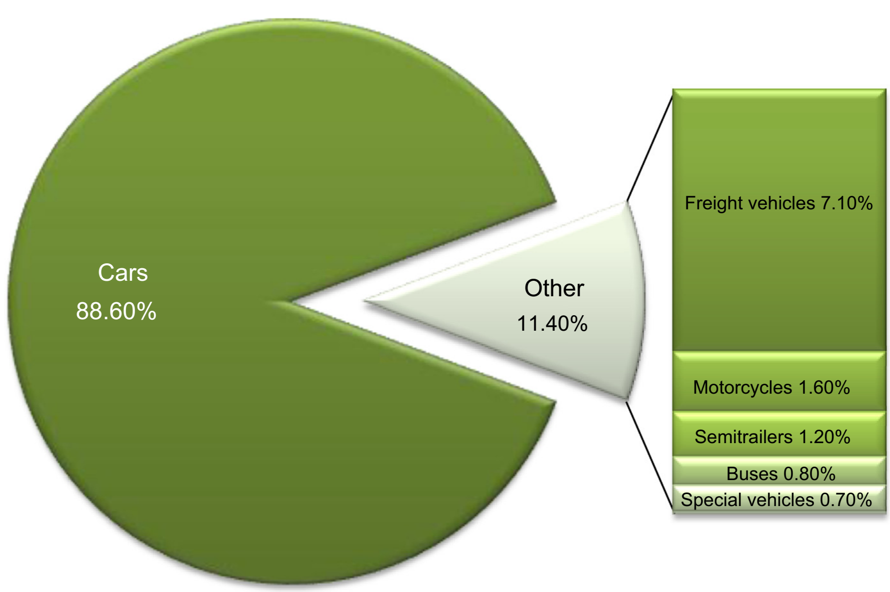


Fig. 2. Road vehicles [33].

Table 1
The total number of road transport vehicles and motorcycles registered in 1990–2010 (thousand) [32].

Year	Classification of vehicles according to the UN-ECE			Total
	L1[a]: 2 wheels, engine < 50 cc or max speed < 50 km/h **L2**[a]: 3 wheels, engine < 50 cc or max speed < 50 km/h **L3**: 2 wheels, engine > 50 cc or max speed > 50 km/h **L4**: 3 wheels – asymmetric, engine > 50 cc or max speed > 50 km/h (motorcycle + sidecar) **L5**: 3 wheels – symmetrical, max weight < 1000 kg., engine > 50 cc or max speed > 50 km/h	**M1**: max. eight seats in addition to the driver's seat	**N1**: max mass ≤ 3.5 t **N2**: max mass > 3.5 t – ≤ 12 t **N3**: max mass > 12 t **M2**: max mass ≤ 5 t **M3**: max mass > 5 t	
1990	192.1	493.0	105.9	791.0
1991	181.2	530.8	114.0	826.0
1992	177.5	565.3	129.5	872.3
1993	180.5	609.1	106.4	895.9
1994	162.8	652.8	111.2	926.8
1995	19.2[b]	718.5	125.9	863.6
1996	19.4	785.1	104.8	909.3
1997	19.1	882.1	108.6	1009.8
1998	19.3	980.9	114.6	114.8
1999	19.5	1089.3	112.2	1221.0
2000	19.8	1172.4	113.7	1305.9
2001	20.2	1133.5	115.6	1269.3
2002	21.0	1180.9	120.9	1322.9
2003	21.9	1256.9	126.1	1404.8
2004	22.9	1315.9	130.1	1468.8
2005	24.0	1455.3	137.3	1616.6
2006	25.5	1592.2	150.7	1768.4
2007	35.3	1587.9	161.6	1784.8
2008	45.6	1671.1	163.9	1880.6
2009	51.4	1695.3	159.7	1906.3
2010	56.3	1691.9	147.2	1895.3

[a] Excludes those with max speed < 25 km/h and fitted for invalid drivers.
[b] Re-registered motorcycles.

a 12.4% increase (4.55 TJ) in diesel fuel consumption by road transportation, whereas consumption of motor gasoline decreased by 2.9 TJ and liquefied petroleum gases by 1.7% (0.12 TJ) [34]. On the other hand, surface (road) transportation contributes a relatively small portion of the total SO_2 emissions as well as sulfur dioxide outputs are less uncertain than those of most other air pollutants (NO_X, PM, NH_3) because emissions depend largely on sulfur contents rather than on combustion conditions [35,36] such as the fuel/oxygen ratio, temperature and pressure.

The total ammonia (NH_3) emissions increased by approximately 485.5% from 1990 to 2010. Passenger cars are the most dominant in the ammonia emissions production. The newer cars fulfilling the EURO limits emit till 50 times more ammonia than the older ones [36]. Thus the gradual change of Lithuania's vehicle fleet causes the significant increase of ammonia even though the limited pollutants like sulfur dioxide, non-methane volatile organic compounds (NMVOC) and carbon monoxide (CO) have decreased dramatically since the early 1990s. According to the calculation ammonia emission from the transport sector increased from 0.03 Gg NH_3 in 1990 to almost 0.17 Gg NH_3 in 2010. The growing tendency is shown in Fig. 3. Although the increase in NH_3 emission looks menacing from up-close, it is only an insignificant part (0.33%) of the total NO_X emission generated by the transport sector in 2010. The reduction of other pollutant emissions over the period 1990–2010 has been very significant indeed: NO_X—44.8%; NMVOC—70.6%; TSP—24.7%; CO—81.5% and polycyclic aromatic hydrocarbons—5.6% [34].

Emissions of heavy metals (HMs) are shown in Fig. 4. The most common HMs emission in LT include lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), copper (Cu), zinc (Zn) and selenium (Se). They depend on metal content in fuel; therefore, emissions were calculated according to consumed fuel. Liquefied petroleum gas (LPG) does not contain HM; therefore, there are no HM emissions from road transport using LPG [34].

In the 1992–1994 HMs emissions in LT have dramatically decreased, while later pollutant emission trends show a clear tendency to increase modestly since 1995, followed by a stronger increase after 2000 [33,34,37]. Notwithstanding this fact, compared to emitted amounts of lead in 1990, emission in 2010 decreased for 98.4%. Emissions of cadmium and selenium decreased for 50.1% in comparison to emissions in 1990. The atmospheric levels of Pb and Cd from the transport sector are generally low in Europe with few overflows of limit or target values [38–40]. This reduction has been made by a combination of specifically targeted legislation and improved controls and abatement techniques in the car industry [38]. The promotion of unleaded petrol fuel within the EU member states though has particularly contributed to these reductions [38–40].

2.1.2. Ex-fleet vehicle market

Lithuania imports significant numbers of used vehicles, including both 9–13-year-old and above 13-year-old automobiles (see Fig. 5) [41]. The top four exporting countries are Germany (approx. 50% of all exports of second-hand vehicles), France, Italy and the UK. All four have the same likeness—net exports of used vehicles (see Fig. 5). Also, an average of 10% of all automobiles imported and temporarily registered in LT come from the United States [42]. Owners of used automobiles intend to use them for a short period until they are sold or finally registered or leave the territory of Lithuania. The Republic of Lithuania has the exclusively large sales market of second hand vehicles which serves as a center of attraction of buyers from Belarus, Paland, Latvia, Russia, Kazakhstan, Tajikistan and other countries. The long-introduced idea of free market, ignoring the principles of consistent development, created ideal conditions for the transport system to evolve to a highly unbalanced system with overfilled types of transportation with negative environmental effects (see Fig. 5) [42].

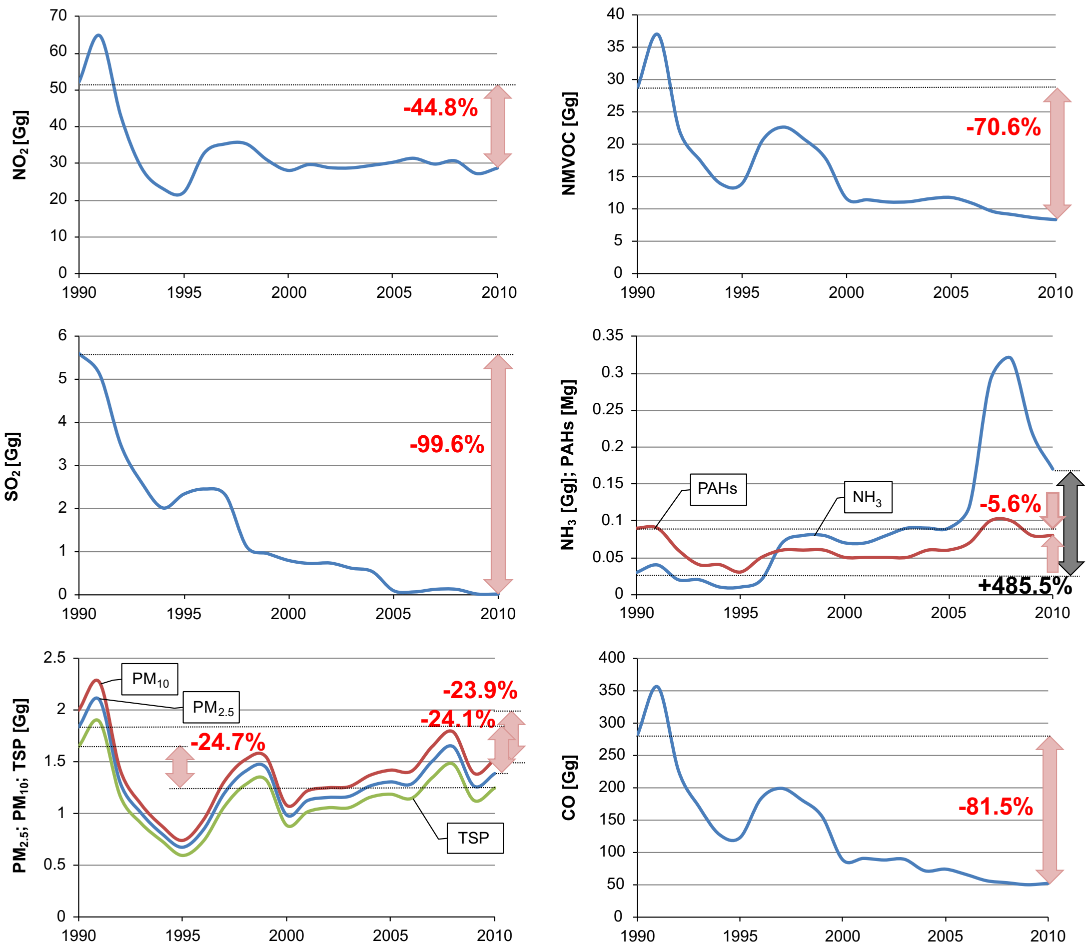


Fig. 3. Road transport emissions 1990–2010 [34].

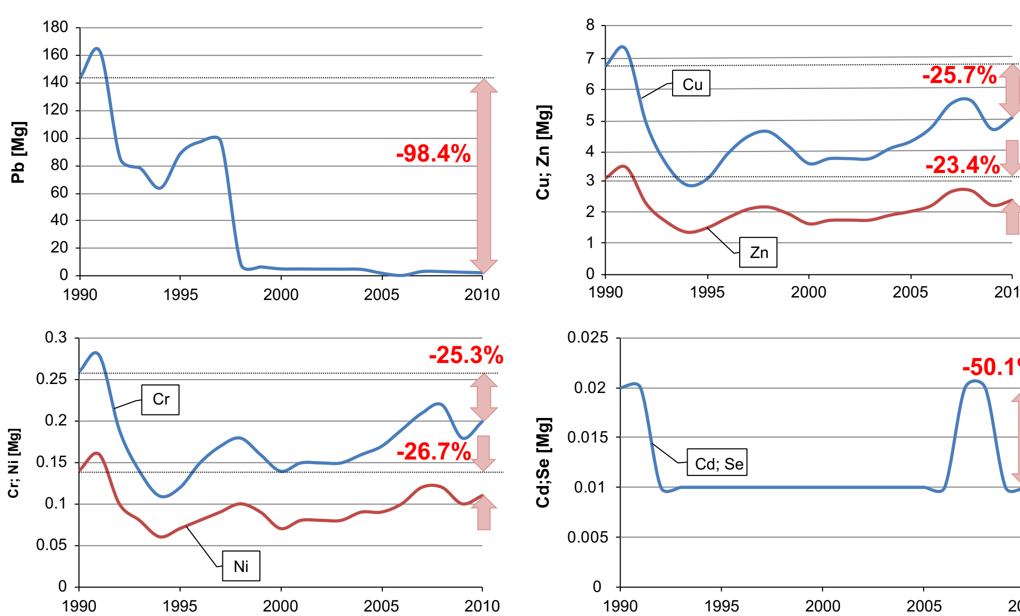


Fig. 4. HM emissions from road transport 1990–2010 [34].

The prediction of the second hand vehicle fleet emissions of CO_2 is usually based on computer modeling of the fleet structure. The relevant parameter for emissions is the vehicle technology described by engine type and emission class. The most important parameter when describing used automobiles fleet is scrappage (as a function of the vehicle's age) because an increasing age leads to an increased probability of higher emission levels [41]. As described by [43,44], three different methodologies are available

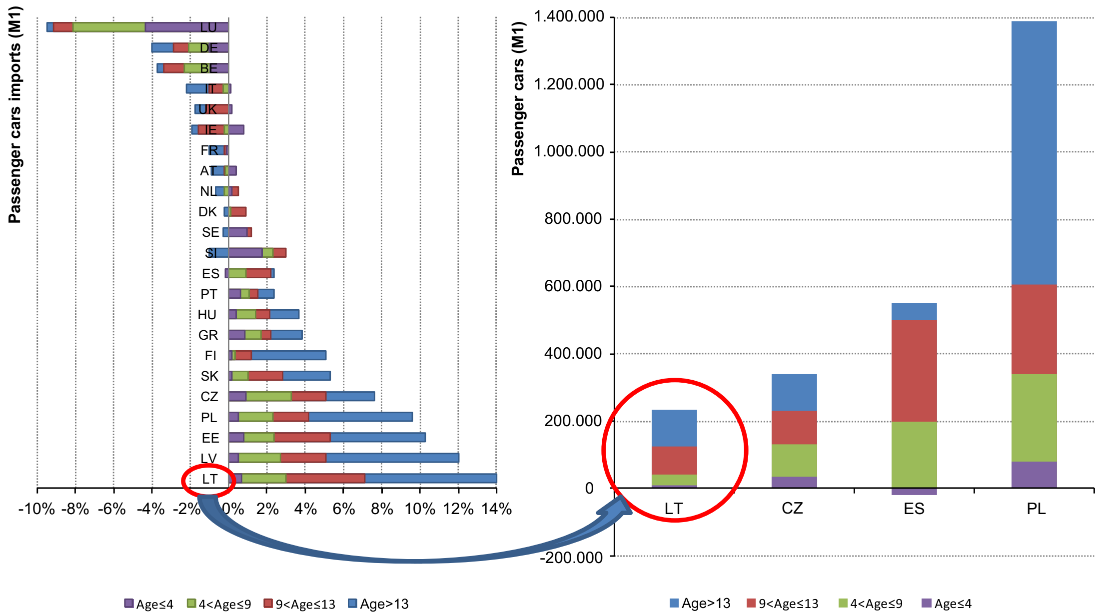


Fig. 5. Net vehicle imports (average 2004–2009) and the largest net importers of vehicles (average number of vehicles 2004–2009) [41].

Table 2
Common applications for various off-road diesel engine size categories [46,47].

Off-road diesel engine size categories	Common applications
0–30 kW	Commercial mowers; mobile welders
30–100 kW	Bulldozers; fork lifts; agricultural tractors
100–250 kW	Tractors; backhoes; excavators; military trucks; wheel cranes; high-mobility multipurpose wheeled vehicle HMMWV
250–1000 kW	Tractors; combines, road graders; wheel cranes; high-mobility 8 × 8 multifunctional SISU E11T combat support armoured trucks; armoured personnel carriers
> 1000 kW	Generator sets; off-road trucks; crawlers

Table 3
Balance of transportation fuels used for off-road vehicles, TJ [32].

	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Diesel fuel													
In agriculture	14277	4207	1327	1253	1384	1385	1385	1362	1325	1429	1487	1354	1444
In construction	2507	935	613	534	565	547	495	589	601	615	670	367	382
In industry	2124	1827	510	471	321	331	381	499	453	378	263	196	190
Gasoline fuel													
In agriculture	440	307	170	91	93	78	70	53	59	62	52	41	43
In construction	439	176	101	53	42	42	45	69	56	47	50	34	28
In industry	44	88	48	15	16	28	21	31	30	21	28	18	15
LPG													
In agriculture	230	46	19	13	15	29	37	38	41	43	43	46	41
In construction	92	46	74	64	79	82	95	77	93	94	133	98	122
In industry	–	–	201	179	169	158	176	229	292	324	292	250	273

to assess the vehicle scrappage rates: (1) a logistic function to estimate the survival rate of automobiles based on the average lifetime for different light-duty vehicles, (2) a Weibull distribution based on attrition rates of the car fleet, and (3) quantifying engineering scrappage resulting from vehicle aging which reflects physical or “built-in” deterioration.

To solve effectively this problem, co-authors of [45] propose using a variable value for $\varphi(k)$ (a modified Weibull distribution with two additional parameters), adjusted to the modeling data according to a fitting law of the type

$$\varphi(k) = \exp\left[-\left(\frac{k+b}{T}\right)^2\right];\ \varphi(0) = 1$$

where $\varphi(k)$ is probability that a vehicle will survive k years after its registration, where k is the age of the vehicle, b is the failure

steepness for the vehicle ($b>1$ implies that the failure rate increases with time) and T is characteristic service life for the vehicle.

For the prediction it is assumed that vehicle technology is a function of the age of a vehicle. Hence, to predict the emission levels of second hand vehicles it is useful to know the age distribution of the country's fleet [41].

2.1.3. Road transport and fuels

Roads will continue to be the primary mode of transport for freight and passengers in Lithuania in the foreseeable future. Virtually all passenger and freight vehicles on LT roads use petrol, liquefied petroleum gas or diesel fuels. 55% of fuel used in the transport sector is diesel oil [33]. In the private passenger car sector, liquefied petroleum gas and petrol have been favored over diesel, though the popularity of private diesel cars has increased markedly over the last decade and half (1995–2010) in LT. For heavy duty vehicles (buses and trucks), diesel has been the dominant fuel because it leads to longer engine life, fuel economy and lower cost of fuel. Biofuel use in 2009 amounted to 64.6 thous. tonnes, representing a 4.16% share of total transport fuel consumption in LT. Fuel consumption for transport is explained in more detail in Chapter 3.2.

2.2. Off-road transport subsector—situational analysis

Off-road diesel engines are used in a wide variety of applications including construction, farming, industrial, forestry and military combat machines. Unlike on-road vehicles, the off-road diesel category applies to a very broad range of engine sizes, types of equipment and power ratings. Common applications for each of the major off-road diesel engine size categories are given in Table 2.

In Lithuania, the dominant off-road transport fuel is automotive diesel. A major consumer of diesel is the agriculture sector (see Table 3), where it is used in heavy duty transport means driven by diesel engines. According to the data of the State enterprise Agricultural Information and Rural Business Centre, in 01 July 2011 the number of tractors and combine harvesters working in the fields of the Republic of Lithuania reached ~235 thous. units and ~14 thous. units, respectively. The number of tractors in use nearly doubled during the last five years since 2007 (~113 thous. units). Relatively high level of the European Union support was the major cause for obtaining new agricultural machinery.

Fig. 6 illustrates GHG emissions from the limited use vehicles which are used solely for the purposes relating to agriculture, horticulture and forestry [32]. As can be seen, in 1990, this category of off-road vehicles generated more than four times as much CO_2 as it emits in 2010. Over the same period, N_2O and CH_4 emissions decreased by 72.6% and 44.0%, respectively. While CH_4 intensity has decreased, methane emissions have increased in real terms by around 77.0% between 2000 and 2010.

Construction and industry are other sectors that rely extensively on liquefied petroleum gas and diesel power. Much of the diesel- and LPG-powered equipment used in the above-mentioned branches (see Table 3) are classified as "off-road". However, less is known about the number and power characteristics of this equipment. Emissions from these sources are only beginning to be controlled [48]. Similar to construction and industry applications, LT provided information for secretariat of the United Nations Framework Convention on Climate Change (UNFCCC) about military mobile combustion for not estimating emissions [49].

For obvious reasons information on military technical capacity is not easily accessible. Over 400 four-wheel-drives (4WD), around 1500 4WD medium trucks and about 200 HMMWV (high mobility multipurpose wheeled vehicles) had been in use in the military of LT in 2008 [50]. The Duke Vaidotas forward Support Battalion serves as the basis of the military transportation service. This battalion is responsible for the transportation of dangerous and other military loads, the support of transportation for military units, for controlling the movements of military transport and for the technical maintenance of military vehicles [51]. The Lithuanian Land Force structure also comprises two mechanized infantry battalions and two motorized infantry battalions (mechanized infantry is distinguished from motorized infantry in that their vehicles provide a degree of protection from hostile fire, as opposed to "soft-skinned" wheeled vehicles for motorized infantry) which are responsible for the releasing of pollutants into the atmosphere as well.

Investment in alternative fuels for military purposes is expected to dramatically increase in the coming years. Although the Military Strategy of the Republic of Lithuania is yet to be updated with energy security goals based on the Lithuanian National Energy Strategy, it is expected to follow its foreign ally experiences and seek to build a military that uses less fossil energy and can offer LT reductions of air

Table 4
Modificational complements and operational measures for mitigation of greenhouse gases from navigation [53].

Possible modifications or/and interventions	Measures	Comments/examples
Equipment	Optimizing conventional propulsion	Energy efficiency layout; Avoiding of over-dimensioning; All-electric propulsion
	Employing alternative propulsion	Fuel cell; Solar; Wind (Skysails); Magnus effect (Flettner rotor)
	Energy-efficient equipment	Auxiliary systems
	Recuperation of energy	Heat exchangers
	Onboard information systems for fuel efficient sailing	Econometer
Fuels	Reducing GHG during production of conventional fuels	Reducing sulfur increases GHG
	Using gaseous fuels	Production, storage on land, distribution, storage on board
	Using 1G biofuels	Questionable social effects and storage on board
	Using 2G biofuels	Not yet available
	Using 3G biofuels	Not yet available
Operations	General reduction of speed	**The most efficient measure**
	Avoiding idling of engine	
	Maneuvering, as little as possible	
	Choise of optimal travel routes	

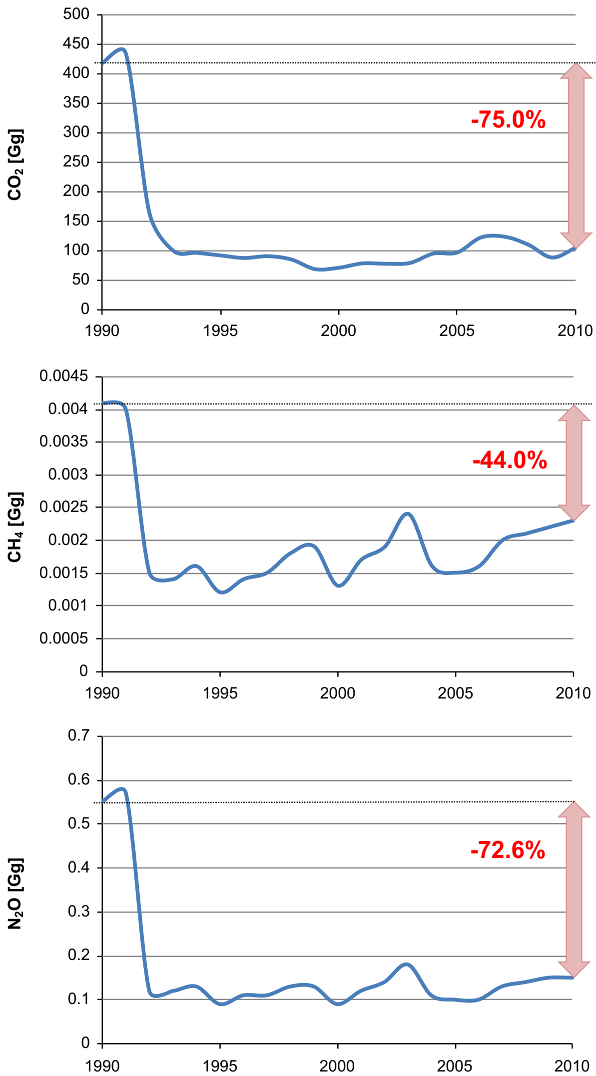


Fig. 6. GHG emissions (Gg) from off-road transport in 1990–2010 [32].

pollution and the potential for use of diversified energy sources [50]. Until currently, commercially available road diesel F-54 (quality standard EN-590) is used in the off-road military transport for the same reasons it is used elsewhere in the economy. In LT, this implies low sulfur diesel fuel (less than 10 ppm S). F-54 provides more power per unit of fuel—an important consideration when fuel must be hauled to distant and sometimes remote sites [52]. Its lower volatility makes it safer to handle than gasoline. In addition to F-54, the army uses small amounts of F-67 (commercial petrol EN-228).

2.3. Railway transport subsector—situational analysis

Railways are one of the earliest forms of motorized transportation in the world. Its history dates back to the early nineteenth century. The diffusion of new technologies throughout the years made it acceptable for citizens of LT: the 150th anniversary of the first railway line constructed in the territory of Lithuania was commemorated in 2011. An opening of this railway track laid the foundation for establishment of a railway network in the country and created the conditions for linking LT with the railway system in Europe.

Because of geographical location, LT is a transit country on the East–West axis. That led to settling a well developed and efficient railway infrastructure. The state-owned company SC Lithuanian Railways (AB Lietuvos geležinkeliai) manages, maintains and operates all the railway lines in the country which consists of 1749 km of broad gauge railway (4 ft 11 5/6 in) (7% electrified) together with 170 km of narrow gauge network (2 ft 5 1/2 in) and 22 km of standard gauge lines. Over almost half a century, railways as an integral part of the Lithuanian transport network play an important role in facilitating trade. The number of motorized railway vehicles in operation totaled 384 units in 2011, out of which 271 are diesel locomotives and 131 are diesel railway vehicles (see Fig. 7). The number of diesel railway vehicles decreased by 41.75% in 2010 compared to that in 2000 [13].

Between 2005 and 2010, the railway shares in both freight and passenger transportation fell to about 48.1 mln. tonnes (−2.4%) and 4.63 mln. passengers (−35.1%) in 2010 from levels of 49.3 mln. tonnes and 6.72 mln. passengers in 2005 (see Fig. 7). The state-owned company responsible for railways services, SC Lithuanian Railways, had been losing passenger volumes transported by trains as well as marked shares over the last 10 years [13]. During 2000–2010, intercity passengers declined by 50.7%. Moreover, in 2010, national passenger transport by rail accounted for only 0.9% of total national passenger transport. Freight services were less adversely affected, with a sizeable hike in transportation volumes in 2000–2005 (+60.2%) and drop of 12.7% during the period 2008–2010 (see Fig. 7). Despite the slowdown in carriage of passengers, the sector offers the most energy-efficient performance and is constantly improving, in terms of both passenger km (pkm) and tonne km (tkm).

Each of these direct factors was the result of meaningful reduction in greenhouse gas emissions, whose evolution during 1990–2010 is provided in Fig. 8.

The statistics dataset [13] shows that CO_2, CH_4 and N_2O all increased sharply in 1995 [13] (after the end of an economic blockade of Lithuania initiated by the Soviet Union), contrary to any of the 5 consecutive years in the first quinquennium of the nineties, largely due to higher diesel oil consumption. In 2011, the data compilation [13] for carbon dioxide CO_2 [GHG], methane CH_4 [GHG] and nitrogen dioxide N_2O [GHG] emissions from rail transport announced, respectively, 47.0%, 46.1% and 46.7% reduction below their 1990 levels.

While rail is the most nature-friendly transport mode, diesel-powered locomotives and railway vehicles remain the weak link in the subsector. In a long-term perspective, the Lithuanian railway sector endeavors to meet new challenges such as increasing energy prices and stricter environmental frameworks set by the EU. Change in the mode of travel from automobile to rail can reduce primary energy use by 30–70%, while switching container freight traffic from road to rail can reduce primary energy use by

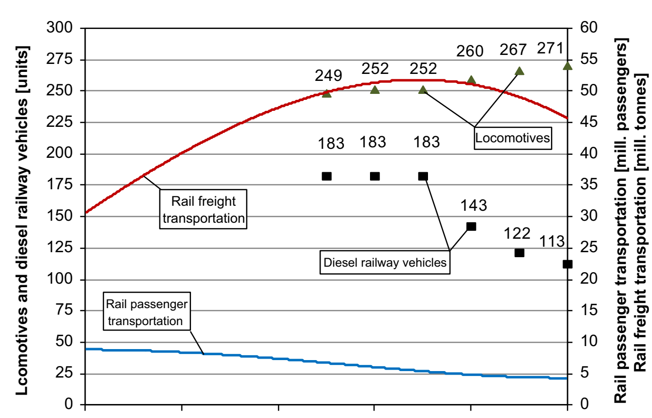


Fig. 7. Passenger and freight rail transportation (1990–2010) and dominant rolling-stock.

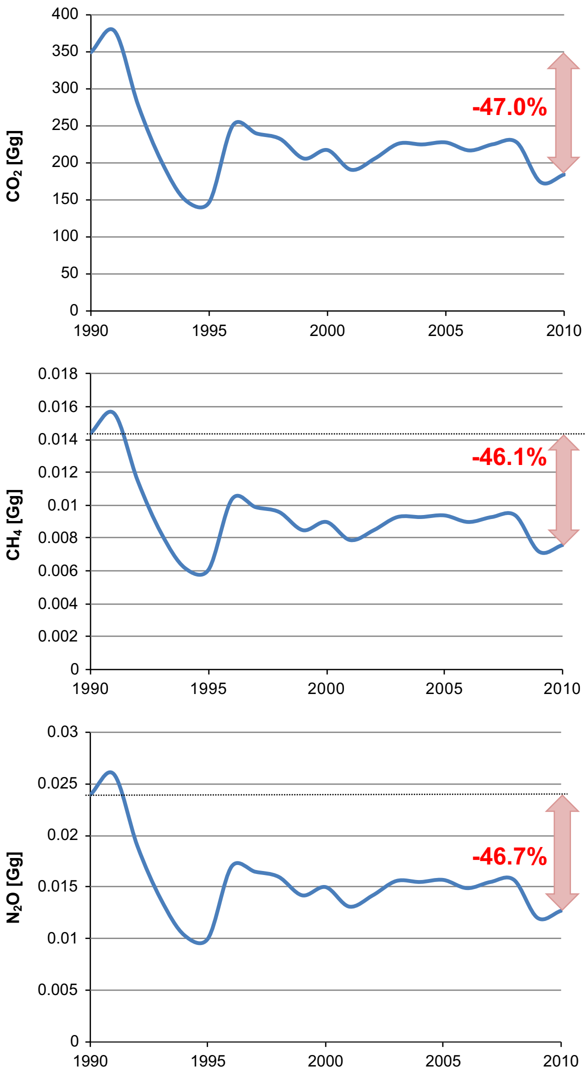


Fig. 8. GHG emissions (Gg) from railway transport in 1990–2010 [32].

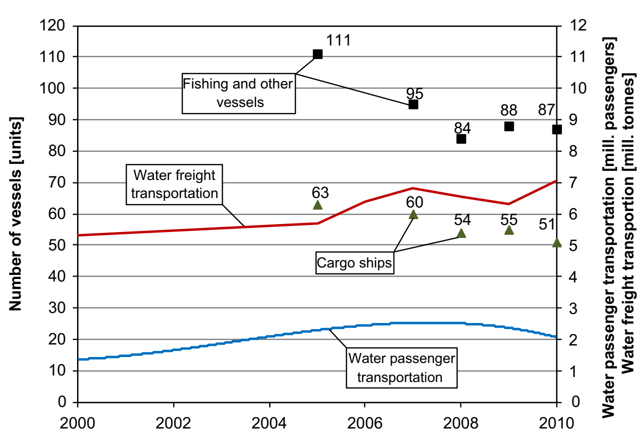


Fig. 9. Passenger and freight water transportation (1990–2010) and dominant types of vessels.

30% [48]. The percentage of GHG emission reduction is more than this value if railways are powered with electricity from renewables [48]. Opportunities to further reduce rail energy use include reducing train weight, lowering its aerodynamic drag and rolling resistance, coupled with the wider application of more efficient propulsion systems and implementation of the regenerative breaking systems.

2.4. *Marine transport subsector—situational analysis*

Lithuania has a national and international navigation component of their transportation sector which includes sea-going, in port and inland waterway vessel activities. Rivers and lakes in LT have been long used as waterways although, with the exception of the longest river Nemunas (total length 973 km, 475 km of which is in LT), currently they are not very suitable for navigation.

The Baltic Sea washes the country's 99 km coastline on the west. It is one of the most heavily trafficked seas (from 53°N to 66°N latitude and from 20°E to 26°E longitude) in the world with more than 730,000 vessel movements per year or approximately 2000 maneuvers per day. In contrast to inland transport, sea waterway transport is a very important transport mode for LT, which allows improving and ensuring sustainable transportation.

Both the size in number of ships and the size of ships, especially freighters and motor fishing vessels, have been reducing during the last few years, and the trend is expected to continue. In 2010, the number of cargo ships and fishing vessels in LT reduced to 51 and 87, respectively, while it was 63 and 111 in 2005 (see Fig. 9). The Lithuanian fleet reduced by 20.5% since 2005 and by December 2010, there were 138 commercial ships in service, with dry cargo ships accounting for 0.359 mln. deadweight tonnes (dwt), ro-ro passenger ships with 0.137 mln. dwt, ro-ro cargo ships with 0.023 mln. dwt and fishing vessels with 0.071 mln. dwt [13]. However, according to the Statistical yearbook of Lithuania 2011 [13], by the end of 2010, Lithuania's water freight transportation volumes had reached 7.8 mln. dwt (sea transport 6.8 mln. dwt, inland waterway transport 1.0 mln. dwt), an increase of 2.4 mln. dwt over 2005 (sea transport 2.3 mln. dwt, inland waterway transport 0.1 mln. dwt).

Historically, the annual numbers of temporary passenger arrivals and departures by Klaipeda State Seaport (the northernmost ice-free port on the Eastern coast of the Baltic Sea) have been highly variable. Three basic groups of passengers use the Baltic Sea for traveling: business travelers, cruise and shopping tourists, and tourists. In fact, inland waterborne and seaborne passengers do not constitute a substantial proportion of total passenger movements to and from Lithuania. Over the last two decades, local government and the private sector increased their investment in water passenger transportation and passenger shipping capacity in LT grew continuously until the first-world debt crisis of 2007–2010 (see Fig. 9).

Shipping, just like any other economic activity driven by market forces of supply and demand, will face serious risks from climate change, with risks derived from changes in transport demand: fossil fuels, which constitute perhaps the most important cargo for navigation, will be replaced by other fuels or renewable sources of energy. Although navigation is not a main driving force to increase climate change caused by GHG emissions, the navigation sector should evaluate the possibilities of contributing to a reduction of anthropogenic GHG emissions to emphasize navigation as an environmentally sound mode of transportation [53]. Marine engines emit a lot of different air pollutants, the most important of which is nitrogen, CH_4, particulates and volatile organic compounds. No less important are the greenhouse gas CO_2 emissions.

Multiple measures for the reduction of greenhouse gas emissions from shipping have been identified and are already implemented in many cases. Table 4 includes measures related to improving the efficiency of fuel-handling equipment and the application of various aspects of ship traffic management scenarios, as they provide real potential for mitigation of GHGs. Most of

the measures can, to varying degrees, be applied to both maritime and inland navigation [53].

The study [53] identified significant potential for air pollutants reduction by technical measures, which can be easily implemented, and by operational measures, which are more effective. Vessel speed reduction is seen as the single most effective measure to reduce GHG emissions from water transport.

In 2010, LT CO_2 emissions from water-borne navigation totaled 17.13 [Gg] (see Fig. 10). It rose by 3.7% from 2009 to 2010. This increase was primarily due to an increase in water freight transportation output resulting in an increase in fossil fuel consumption across the sector. Since 1990, LT shipping-related carbon dioxide and greenhouse gas methane emissions have increased by 9.8% and 14.3%, respectively, while the trend for nitrous oxide emission remains the same.

Over the 20-year period (1990–2010) GHG emissions from the marine transport subsector in Lithuania have continued to increase whilst the GHG emissions from other transport subsectors have stabilized or begun to fall. Hereby, the observed long-term trends of emissions do not always reflect the current situation. Many studies have documented [6,13,31–34,47,54] that the pollution from all transport subsectors has grown in LT after 2004, although the country has joined EU and has implemented environmental requirements including those for the transport sector.

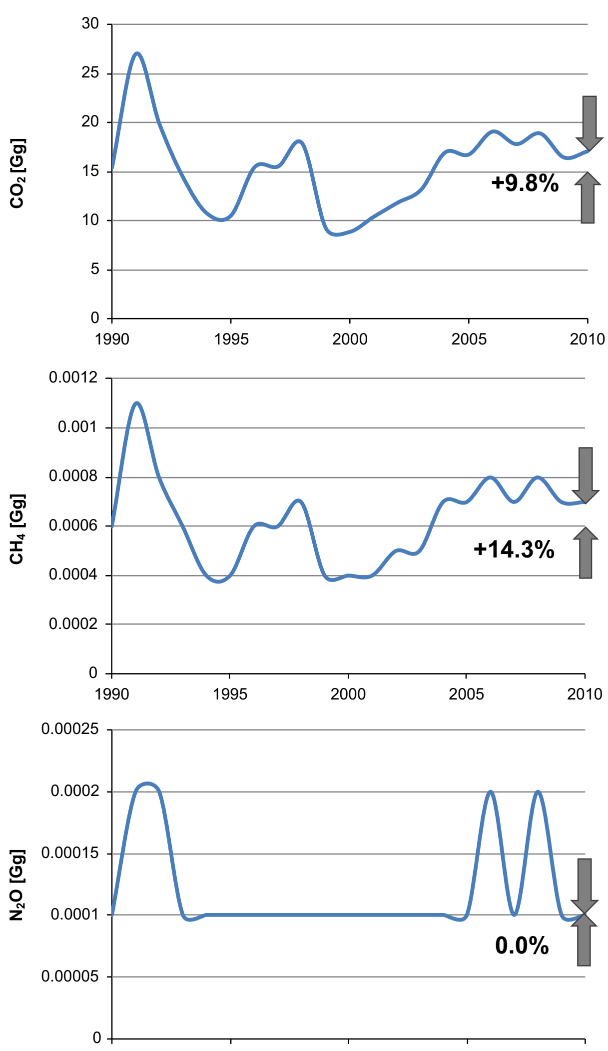


Fig. 10. GHG emissions (Gg) from water transport in 1990–2010 [32].

2.5. Air transport subsector—situational analysis

This section provides background information on the size, geographic location, capacity development, aviation fuel consumption and ecological aspects of the Lithuanian air transportation industry, which also includes establishments engaged in operation of aircraft for domestic and foreign transportation as well as operating airports, flying fields and terminal services.

LT's airline industry began in 1921 and it is not large. It in particular provides transportation of freight, mail, foods having short shelf life and passengers. Currently, LT is one of the few EU countries that does not have its national air carrier. The former national airline company Lithuanian Airlines LAL was established on 20 September 1991, shortly after Lithuania's independence from the Soviet Union and inherited the Vilnius-based Russian Airlines fleet "Aeroflot" of Antonov (four An-24; three An-26), Yakovlev (twelve Yak-40/42) and Tupolev (seven Tu-134) aircraft, but rapidly replaced them with Saab 340, Saab 2000 turboprops, Boeing 737 and Boeing 757 jets. After successfully entering the international regular flight market in the early nineties, LAL has gone bankrupt because of unsuccessful privatization.

As of 2010, there were 39 civil landing areas (e.g., private, municipality-owned and state-owned aerodromes as well as aerodromes belonging to aero clubs, etc.) in LT. At the moment 3 international airports are operating in the country, each named after their principal city: Kaunas (54°57′50″N 024°05′05″E), Palanga (55°58′24″N 021°05′38″E) and Vilnius (54°38′13″N 025°17′16″E) airports. They are operated by state-owned enterprises under the supervision of the Ministry of Transport and Communications. The Vilnius International Airport (VNO) is the main airport in Lithuania; about 80% of passenger and aircraft movements in LT are operated through VNO.

In 2010, a total of 735 aircraft were registered in the Lithuanian Civil Aircraft Register, including 281 airplanes, 121 experimental aircraft, etc. (see Fig. 11). International airports suffered severe consequences of the economic crisis; however, during 2010 almost 0.828 million passengers were served (see Fig. 11). Compared with 2007, flows of passengers have increased by as much as 9.5% in the airports. Lithuanian citizens have come to rely on domestic and international air transportation more and more every year. The number of cargoes in LT airports has decreased dramatically over the last five years and it remains below 2000 levels (see Fig. 11).

Table 5 shows the evolution of fuel consumption in the LT air transport subsector from 1990 to 2010. Fuel efficiency can be measured in terms of units of traffic (passenger-kilometers or revenue tonne-kilometers) or capacity (seat-kilometers or available tonne-kilometers). The need for LT aviation to be more fuel efficient will be driven in the coming years both by high fossil fuel

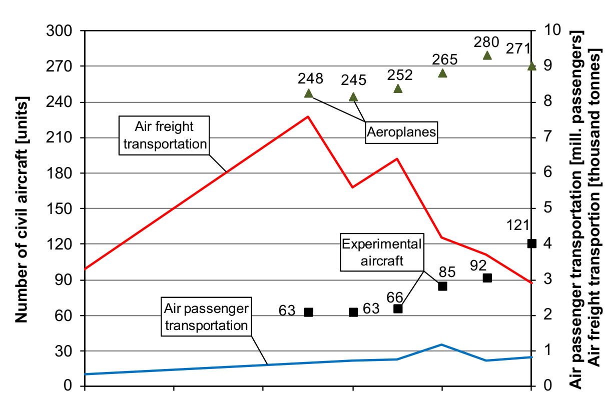


Fig. 11. Passenger and freight air transportation (1990–2010) and dominant types of civil aircraft.

Table 5
Balance of transportation fuels used for aviation, TJ [32].

	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Kerosene type jet fuel													
In aviation	5642	1723	1078	478	626	961	641	2100	2365	2993	3384	1696	2237
Gasoline type jet fuel													
In aviation	–	–	–	953	634	396	988	3	–	–	–	–	–
Aviation gasoline													
In aviation	–	–	14	22	22	22	22	20	20	22	23	18	18

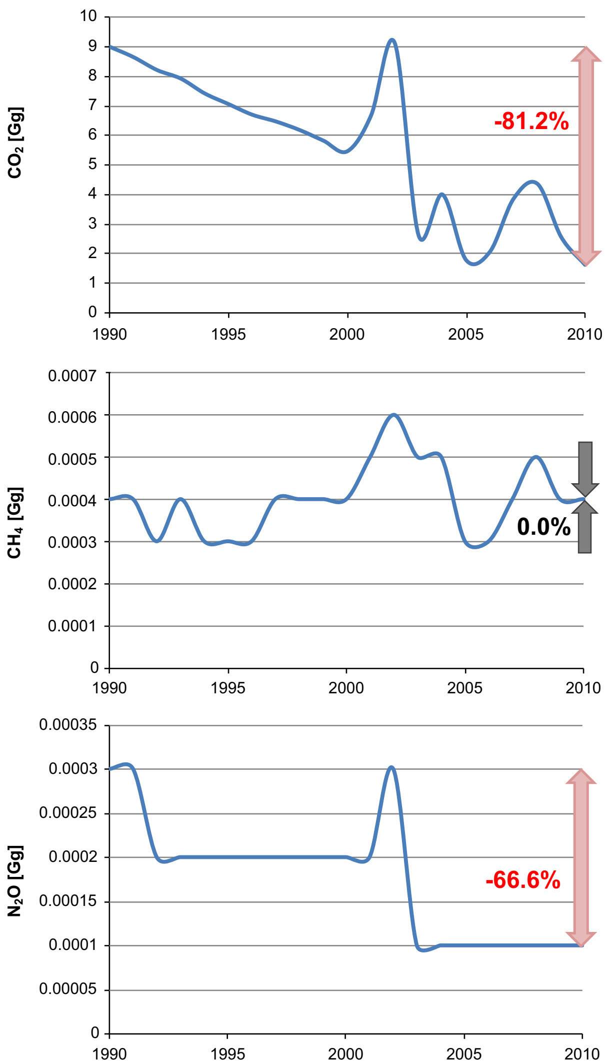


Fig. 12. GHG emissions (Gg) from air transport in 1990–2010 [32].

prices and by environmental taxes or cap-and-trade. The analysis of world tendencies of aviation industries development allows predicting that fuel efficiency per revenue passenger kilometer reductions between the period 1959–1998 came from better specific fuel consumption (57%), improved lift to drag ratio (22%), load factor (17%) and seating capacity (4%) [55,56]. The first two are related to aircraft selection, the latter two to business models and service standards [56].

Local carriers used for air passenger transportation on domestic and regional flights are identified as greenhouse gas emission sources within the air transportation subsector. After achievement of the 1990-levels of CO_2 emissions in 2001, carbon dioxide emissions decreased by 5.63 times in 2010 (see Fig. 12), which is unprecedented in the last two decades [32]. The small contribution of aviation CO_2 emissions is, however, showing a tendency to increase, and the small amounts of carbon dioxide being emitted by aircraft now will remain in the air for many years to come [7].

The Strategy of the Activity of Civil Aviation of Lithuania examined various scenarios of air traffic and emissions growth. Efficiency in terms of emissions per available tonne-kilometer can be captured by applying new technologies to aircraft or by improved operational performance [55,56]. The issue of alternative fuels has been given a lot of prominence recently in LT with some experimental trials being carried out by a number of scientists as well. Research continues into this area and the aviation industry is hoping that other industries which could benefit from the renewable fuels will contribute to this research [56].

3. Description of the (bio)fuel market in Lithuania

3.1. Final consumption of petrol, diesel and biofuels for transport

Mobile sources account for a large fraction of fossil fuel combustion in Lithuania. Of this the largest source is road transport. The interactions between fuel (liquefied petroleum gas, diesel and gasoline), transport means and the atmosphere are complex, yet critical. It is of crucial importance that these interactions are clearly understood within the specific context of the local environment to ensure the achievement of the desired outcome—namely cleaner air—without prejudice to the requirement for affordable transportation [57].

Public Company ORLEN Lietuva (ex. SC "Mazeikių nafta") was and still is the only refinery of oil products in LT. Therefore all oil products sold in LT are either produced by ORLEN Lietuva or imported from abroad. Several joint stock companies, that are JSC Lukoil Baltija (118 filling stations), JSC Lietuva Statoil (75 filling stations), JSC Baltic Petroleum (48 filling stations), JSC Stateta (34 filling stations), JSC "Kvistija" (15 filling stations), JSC "Trevena" (11 filling stations), JSC "Alauša" (9 filling stations), JSC "Skulas" (6 filling stations) and other companies, have import licenses for oil products and are involved in wholesale trade in oil products (year 2012). The aforementioned companies could choose whether to buy oil products from the local refinery ORLEN Lietuva or to rely on imports.

In Lithuania, fuels other than petrol and diesel are insignificant (see Table 6) [13,31,32].

Preliminary data indicate that total transportation fuel consumption in LT in 2010 was 1.512 million tonnes, including 0.296 million tonnes of petrol (12,841 TJ), 1.011 million tonnes of diesel (41,030 TJ) and 0.205 million tonnes of liquid petroleum gas (7554 TJ) [58]. Gasoline consumption in LT transport sector has been fairly static over the period 2002–2006 and remained at

Table 6
Balance of transportation fuels, TJ [32].

	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Diesel fuel													
Production	107712	42490	56232	88234	86146	99692	120024	127985	103670	78465	135302	134283	150168
Biofuel blended	–	–	–	–	–	–	–	119	589	1748	2127	1597	1478
Gross inland consumpton	65222	26174	23625	27538	28650	28436	32285	35481	38123	46422	47586	38406	43308
Final consumption in transport	34289	14489	21476	24894	25976	25882	29721	32515	35362	43721	44808	36197	41030
Petrol fuel													
Production	87988	37709	68838	84279	77453	85113	105530	112699	98505	72271	123381	119393	123626
Biofuel blended	–	–	–	–	–	–	3	35	219	471	714	655	445
Gross inland consumpton	43379	26678	16797	16414	15805	15954	15172	14958	15884	19231	19143	16080	12956
Final consumption in transport	41840	25887	16337	16169	15710	15662	14973	14721	15652	19058	18965	15948	12841
LPG													
Production	12006	7636	11026	19565	19104	17662	21146	21046	18812	13254	18439	12679	12720
Biofuel blended	–	–	–	–	–	–	–	–	–	–	–	–	–
Gross inland consumpton	7222	4276	8785	8847	9898	10765	12026	12723	12700	11903	10727	9735	9519
Final consumption in transport	920	1058	5032	5272	6378	7332	8857	9593	9810	9708	8615	7681	7554
Biodiesel													
Production	–	–	–	–	–	–	82	260	383	917	2390	3873	3299
Gross inland consumpton	–	–	–	–	–	–	29	119	589	1762	1916	1581	1454
Final consumption in transport	–	–	–	–	–	–	29	119	589	1762	1916	1581	1454
Bioethanol													
Production													
Gross inland consumpton	–	–	–	–	–	–	3	35	225	494	656	603	514
Final consumption in transport	–	–	–	–	–	–	3	35	72	200	334	584	436

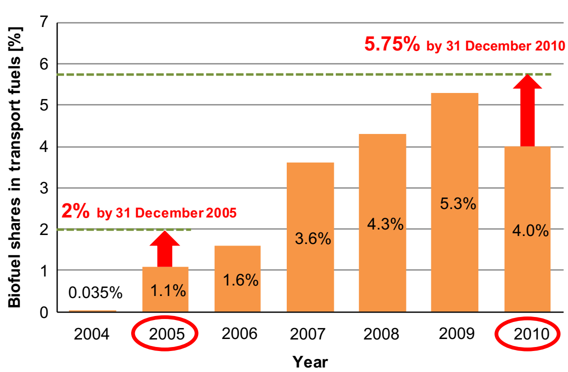


Fig. 13. Share of biofuel in total transport fuel, 2004–2010.

almost the same level during these five years. There has been a fairly steady growth in diesel consumption between 1995 and 2008, which has experienced a 210% increase over the 12-year period (see Table 6).

The main types of biofuel consumed in LT are biodiesel and bioethanol. In 2010, LT imported 3.9 thous. tonnes of bioethanol and 14.2 thous. tonnes of biodiesel. The country exported 24.0 thous. tonnes of bioethanol (pure and blended with fuels), 67.8 thous. tonnes of biodiesel (pure) and 0.8 thous. tonnes of biodiesel blended with mineral fuels. Consumption for transport purposes amounted to 39.3 thous. tonnes of biodiesel (1454 TJ) and 19.1 thous. tonnes of bioethanol (436 TJ) blended directly with mineral fuels [58].

The main Lithuanian market developments in the field of transportation biofuel production could be analyzed from 2004 onwards. The Commission of the European Union initiated a Directive (2003/30/EC) calling for a 5.75% fuel replacement by biofuels (energy base) by 2010. Within a short space of time LT has passed the biofuel Directive into national law. In 2007, a share of 3.6% of biofuels in the total domestic consumption of transport fuels was reached [59]. Fig. 13 shows the consumed quantities from 2004 to 2010.

In fact, the national indicative targets for the bio-based fuel share of all transport fuels up to date have not exactly reached their objectives. It needs to be mentioned that LT has provided small levels of support for biofuel development and future action is required to address them. As of 2009, new challenges arise for local fuel suppliers and producers, as well due to the Revised Fuel Quality Directive (Directive 2009/30/EC). They have to reduce Greenhouse Gas Emissions in fuel, by a total of 6% in 2020 compared with the 2010 level (intermediate targets: 2% by 2014; 4% by 2017; and 6% by 2020) [60]. This will primarily be done by higher level biofuel blending and by continual and steady improvement of refining processes, leading to significant increases in efficiency [61]. Member states may choose to increase this percentage up to 10% by accepting an additional voluntary savings target of 4% [60,61].

3.2. Production capacities and main actors of the biofuel sector

Nowadays, 4 biodiesel plants and 2 bioethanol plants operate in LT (see Table 7) [59].

The largest company in biodiesel production industry in LT is the private limited liability company JSC “Mestilla”. By the end of 2007 the company implemented a large investment project (EUR 38 mln.) and built a new state-of-the-art plant equipped with the most advanced biofuel production technologies in EU [62]. JSC “Vaizga” (ex. JSC “Rapsoila”) is the first industrial biofuel plant established in LT which has been producing biodiesel since 2002; its capacity is 30 thous. tonnes of vegetable oil fatty acid methyl ester (FAME) per year. It is predominantly produced from rapeseed (referred to as “Canola” or *Brassica napus L.*) oil. Canola is cultivated by many local farmers and agricultural companies, but the special seed for the production of FAME is sparsely cultivated. Biodiesel produced in LT can be used both in summer and in winter weather conditions.

Table 7
Biofuels producers and suppliers in Lithuania in 2011 [59].

Seq. no.	Company	Installed capacity, thous. tonnes/yr.
Biodiesel		
1.	JSC "Mestilla" (Kretainio g. 5, LT-94103 Klaipėda. Tel.: +37069726500. E-mail: info@mestilla.lt). Since 2007.07.01.	110
2.	JSC "Vaizga" (ex. JSC "Rapsoila") (Montuotojų g. 2, LT-89101 Mažeikiai. Tel.: +37044368022. E-mail: info@rapsoila.lt). Since 2002.03.26.	30
3.	JSC "Arvi cukrus" (P. Armino g. 65 LT-68127, Marijampolė. Tel.: +37034397810. E-mail: info@arvicukrus.lt). Since 2007.04.01.	12
4.	SV "Obeliai" (Audronių km., LT-42221 Rokiškis district. Tel.: +37068609066. E-mail: info@sv.obeliai.lt). Since 2007.03.01.	8
Bioethanol		
1.	JSC "Biofuture" (Šilo g. 4, LT-99149 Šilutė. Tel.: +37044161121). Since 2008.07.01.	40
2.	JSC "Kurana" (Mūšos g. 19, LT-39103 Pasvalys. Tel.: +37045134500. E-mail: info@kurana.lt). Since 2008.07.01.	20

Table 8
National measures aimed at promoting the production and use of biofuels [58,63]

Government policies	Legal environment
Lithuanian Law on biofuels, Biofuels for Transport and Bio-oils (Source: Official Gazette 2000, No 64–1940; Official Gazette 2004, No 28–870; Official Gazette 2009, No 10–360).	By December 31st 2010, biofuels for transport (biodiesel, bioethanol, bio-ETBE) must account for 5.75% (energy content) of all gasoline and diesel fuel placed on the LT domestic market.
Lithuanian Law on the tax on environmental pollution (Source: Official Gazette 1999, No 47-1469; Official Gazette 2005, No 47-1560; 2009, No 61-2404)	Natural and legal persons who own motor vehicles suitable for running on biofuels (according to established standards) and who have submitted documents confirming the use of such biofuels are exempt from the tax on environmental pollution from mobile sources.
Rules for financing the development of biofuel production. Approved by Order no 3D-658 of the Minister for Agriculture of the Republic of Lithuania of 9 September 2009 (Source: Official Gazette 2009, No 110-4686)	A refund is given for part of the price of rapeseed oil intended for the production of RME/REE and of rapeseed and cereals purchased for the production of dehydrated ethanol. The aid amount is as follows: rapeseed – EUR/t 46.38 (LTL/t 160); cereal grain – EUR/t 33.0 (LTL/t 114).
Article 27 of the Lithuanian Law on excise duties (Source: Official Gazette 2010, No 45-2174)	Zero rate of excise duty is applied to anhydrous ethanol.
Article 40 of the Lithuanian Law on excise duties (Source: Official Gazette 2001, No 98-3482; Official Gazette 2010, No 45-2174)	For oil products and other combustible liquids that exceed the mandatory percentage of bio-additives laid down by the Law on State Stocks of Petroleum Products and Crude Oil (Official Gazette, 2002, No 72-3008), the rate of excise duty is reduced at a rate proportionate to the amount of bio-additives in excess of the mandatory percentage laid down by Law. For above-mentioned products in which the proportion of additives of biological origin is 30% or higher, the rate of excise tax is reduced in proportion to the percentage of bio-additive in the product.
Order No 4-249 of the Minister for the Economy of the Republic of Lithuania of 13 June 2008 (Source: Official Gazette 2001, No 37-1269; Official Gazette 2008, No 70-2669)	The Rules governing trade in oil products in the Republic of Lithuania specify that oil products supplied to the LT's domestic market must comply with the following requirements: (a) from January 1st 2007, 95 RON (research octane number) gasoline must be produced using the additive bio-ETBE, the proportion of which in the blend with motor spirit must be at least 7% (v/v), but not more than 15% (v/v). From October 1st 2008, the proportion of bio-ETBE blended with 95 RON gasoline must be at least 10% (v/v), but not more than 15% (v/v); (b) 95 RON gasoline produced without bio-ETBE must have an anhydrous ethanol content of 5% (v/v) with a permitted tolerance of –0.5% (v/v). The permitted tolerance for anhydrous ethanol (v/v) in E85 is $\pm$0.5% (v/v); (c) diesel fuel (with the exception of class-2 (–22 °C) Arctic diesel) must contain 5% (v/v) of FAME (produced from vegetable oils or fats of animal origin) with a permitted tolerance of –0.5% (v/v). The quantity of fatty acid methyl ester in diesel fuel may exceed 5% (v/v) if the diesel/biodiesel blend meets the mandatory quality indicators for diesel; (d) Petroleum products supplied for domestic consumption from public stock markets must contain a matter that interacts with biological systems (biomaterials).

The main raw material for the production of bioethanol in LT is cereal grain of wheat (*Triticum aestivum L.*), rye (*Secale cereale*) and triticale (*Triticosecale*). Dehydrated bioethanol intended for transport fuels currently is used in two ways: (i) by blending it with gasoline mechanically and (ii) by producing 1G synthetic fuel bio-ethyl-tertio-butyl-ether (bio-ETBE), which contains 47% of ethanol. In 2008, SC "Mažeikių nafta" (pre-PC ORLEN Lietuva) produced 27.1 thous. tonnes of bio-ETBE and blended the whole quantity with gasoline in the refinery.

In December 2005, the Šilutė town bioethanol plant was taken over by JSC "Biofuture"—the company established after reorganization of the oldest Lithuanian alcohol producer SC "Stumbras". The company recently celebrated its 8th year of operation, distinguishing itself as the country's first bioethanol plant. Since 2005,

JSC “Biofuture” has increased bioethanol production capacities several times in order to satisfy the early market demand that is in the process of formation and is increasing rapidly both in LT and in EU.

The second company, which entered the local market only in 2009, is JSC “Kurana”. It is a first-generation ethanol plant situated in Pasvalys town, designed to produce 20 thous. tonnes bioethanol per year from wheat grain. To eliminate the dependency on natural gas and to enhance the overall energy balance of the ethanol plant, an Integrated BioRefinery (biogas and separation plants) has been designed and built adjacent to the ethanol plant by Renew Energy A/S (Denmark).

4. Implementing sustainability

4.1. Political framework of biofuel sector and existing policy instruments

LT has adopted 36 laws, which directly or indirectly regulate environmental protection and management, and the usage of natural resources and biological resources including those concerning the environmental impact assessment [62]. The general measures for promoting biofuels for transport in Lithuania are presented in Table 8.

The main problem with Lithuanian environmental protection legislation is the patchy nature of the regulation (there is no governmental decision indicated on setting of national fuel economy/GHG standard), from which most other problems arise. Although transport emissions and fuel efficiency are quite new topics of discussions in LT, public awareness is rapidly growing and more efficient and economic automobiles are gaining popularity due to growing congestion in bigger cities.

In 2010, EUR 5.92 mln. (LTL 20.44 mln.) of Lithuanian state funds were earmarked for the development of first-generation biofuel production; 55.6 thous. tonnes of cereal grain (a crop area of 18.5 thous. ha) and 88.25 thous. tonnes of rapeseed (a crop area of 44.13 thous. ha) were bought for biofuel production [58,63]. According to data supplied by the State Tax Inspectorate under the Ministry of Finance of the Republic of Lithuania [63], the excise duty relief permitted under the Law (art. 40(4) and (5)) on excise duties to biofuels sold in the country totaled EUR 1.40 mln. (LTL 4.82 mln.) in 2010. By product, the excise duty relief applied was as follows: EUR 0.403 mln. (LTL 1.39 mln.) for bioethanol blended with motor spirit, EUR 0.631 mln. (LTL 2.18 mln.) for bioethanol (E-15) and EUR 0.362 mln. (LTL 1.25 mln.) for FAME blended with diesel fuel [58,63].

4.2. Retrospective of R&D activities

Originally started by individual enthusiasts in the late 1990s, the idea of application of esthers and alcohols as alternative fuels for internal combustion engines has attracted increasing interest in the scientific community over the last decade in LT (Table 9). Lithuania as a post-soviet country which had a centrally planned economy underwent major changes in 1991, including restructuring and mass privatization of some of the largest companies (distilleries and alcohol refineries among them). Historically it was thoroughly natural for LT that the immediate possibility of partially substituting petroleum fuel by ethanol gained an interest much before biodiesel issues begin to arise. In 1994, upon the request from Panevėžys City alcohol company “Sema”, the Dept. of Road Transport at Vilnius Gediminas Technical University conducted a theoretical research and

Table 9
Research projects (biofuels for use in road transport), financed from EU structural funds during 2004–2011.

Project time-span	Research projects, financed from EU structural funds	Project partners
Lithuanian University of Agriculture (now Aleksandras Stulginskis University)		
2004–2005	ALTENER *Innovative biodiesel.*	Lithuanian University of Agriculture (Lithuania); Austrian Biofuels Institute; Federal Institute of Agricultural Engineering (Austria); Baltic Renewable Energy Centre (Poland); University Rostok (Germany); Slovak Technical University; Institute for Mineral oil products (Austria).
2004–2006	EUREKA E! 3*234 Sustainable processing of waste fats to be used in SME for energy purposes.*	Lithuanian University of Agriculture (Lithuania); Central Petroleum Laboratory (Poland); Institute of Heavy Organic Synthesis “Blachownia” (Poland).
2006–2008	Ap-06-77/07/Ap-06-70/08 *Sustainable production of biodiesel fuel from renewable resources and fatty wastes.*	Lithuanian University of Agriculture (Lithuania); Chang Gung University (Taiwan); Riga Technical University (Latvia).
2007–2009	EUREKA E! 3944. *Development of technology for processing plant oils and spent fats as components of biodegradable lubricants and fuels.*	Lithuanian University of Agriculture (Lithuania); Institute for Fuels and Renewable Energy (IFRE, Poland); Institute of Heavy Organic Synthesis “Blachownia” (Poland); Air Force Institute of Technology (Poland).
2007–2010	EUREKA E! 4018. *Development of technology to manufacture biofuels using Camelina Sativa oil as new raw material base.*	Lithuanian University of Agriculture (Lithuania); Institute of Heavy Organic Synthesis “Blachownia” (Poland); Institute for Fuels and Renewable Energy (IFRE, Poland); Poznan University of Agriculture (Poland); Klaipeda University, Maritime Institute (Lithuania); Lithuanian Institute of Agriculture (Lithuania)
2009–2011	ERA-ARD. *Reduction of impact of biofuel production to food stock.*	Lithuanian University of Agriculture (Lithuania); Institute of Fuels and Renewable Energy (IFRE, Poland); National University of Life and Environmental Sciences of Ukraine (NULESU, Ukraine).
2010–2013	EUREKA E! 5030 BIOGASFUEL. *Development and implementation of a dual-fuel supply system in diesel engines using biogas/pilot dose of diesel fuels.*	Lithuanian University of Agriculture (Lithuania); Warsaw University of Technology/Institute of Vehicles (Poland).
Lithuanian Energy Institute		
2005–2008	EUREKA E! 3590. *Utilization of glycerol fraction from biodiesel plants (USE-GLYCEROL).*	Institute of Heavy Organic Synthesis “Blachownia” (Poland); Lithuanian Energy Institute (Lithuania).
Klaipeda University, Maritime Institute		
2011–2014	EUREKA E! VP1-3.1-ŠMM-06-V-01-003.Camelina-Biofuel *Development of technologies for biofuel production by employing Judra oil as a new base of raw material.*	Klaipeda University, Maritime Institute

Table 10
Alternative transport fuels under investigation in Lithuania during 2003–2011.

Investigated blend ratio	Scientific activity	Year								
		2003	2004	2005	2006	2007	2008	2009	2010	2011
Biofuel groups: Vegetable oils; vegetable oil–fossil diesel blends										
Vegetable oil; Rapeseed oil (RO); RO5; RO10; RO15; RO20; RO25; RO30; RO50; RO75	Combustion theory and modeling; engine bench tests	[64]		[65,66]	[67]	[68]			[69]	[70]
	Policy; reviews and outlooks								[69]	[70]
Biofuel groups: Biodiesel–rapeseed oil blends										
B25RO75; B50RO50; B75RO25	Combustion theory and modeling; engine bench tests					[68]				
Biofuel groups: Biodiesels; FAME–fossil diesel blends										
RME (B100); REE (B100); FAME; Camelina oil methyl ester; B5; B10; B20; B30;	Chemical composition; life cycle assessment		[73,75]	[74,76]	[92]			[86]		
B50; B70	Combustion theory and modeling; engine bench tests	[71]			[77–81]	[82–84]	[85]		[69,89,90]	[70,91]
	On-field tests	[72]		[87]				[88]		
	Policy; Reviews and outlooks					[93]			[6,94]	[7,95]
Biofuel groups: Ethanol; methanol; ethanol–petroleum blends										
	Combustion theory and modeling; engine bench tests	[96]	[97,98]				[99]			
	On-field tests									
	Policy; reviews and outlooks					[93]			[94]	[95]
Biofuel groups: Multi-component biofuels										
D-RME-E; D-REE-E	Chemical composition; life cycle assessment			[100]				[103,104]		
	Combustion theory and modeling; Engine bench tests							[101–104]	[90,103–106]	
	On-field tests							[88,103,104]		
	Policy; Reviews and outlooks							[103,104]		

Abbreviations: D is diesel fuel, RO is rapeseed oil, B is biodiesel, and E is dehydrated ethanol. The figures are mixing ratios by volume.

Table 11
Projections for biofuel demand until 2025 [112,113].

Biofuels demand projections	2015	2020	2025
Biofuel share, (%)	7.88	10.0	15.0
Bioethanol production capacities, ktoe/yr. (thous. tonnes/yr.)	13.03 (20.36)	17.43 (27.23)	27.40 (42.81)
Biodiesel production capacities, ktoe/yr. (thous. tonnes/yr.)	76.15 (88.55)	101.7 (118.26)	159.85 (185.87)
Bio-ETBE production capacities, ktoe/yr. (thous. tonnes/yr.)	67.99 (84.67)	90.82 (113.10)	142.7 (177.71)
Total biofuels, ktoe/yr. (thous. tonnes/yr.)	157.17 (193.58)	209.95 (258.59)	329.95 (406.39)
Fuel consumption in transport, ktoe/yr. (thous. tonnes/yr.)	1995 (1936.89)	2100 (2038.83)	2200 (2135.92)

Note: The applied conversions from applied energy units (tonnes) to tonnes of oil equivalent: 1 t of diesel fuel = 1.1 toe; 1 t of gasoline = 1.05 toe; 1 t of biodiesel = 0.86 toe; 1 t of bioethanol = 0.64 toe; 1 t of bio-ETBE = 0.803 toe.

experimental tests on the exploitational parameters of ethyl alcohol and petroleum with regard to their use for internal combustion engines. The goal was to prove to distillery investors that ethanol additive to petroleum fuel would not harm carburetor engines, and to convince them that spark ignition (Otto) engines could effectively run on oxygenated blends. The research has proven that the combustion process in the unmodified carburetor engine is reliable and stable. Very similar results, though less effective, were received by combusting methanol. In the period 1994–2004, the VGTU experimented with alcohol fuel, including many years of engine testing on the test stand with ethanol, methanol and a variety of blends with petroleum.

Several types of diesel engines running on bio-blends were tested in the laboratories of the Institute of Agricultural Engineering LUA, VGTU, Maritime Institute KU, and LUA from 2003 to 2011 (Table 9). A number of relevant results were obtained, which show that in some cases there are great differences in the fuel consumption and emission test results when different-sized stationary engines are directly compared. And to verify the reality on the grounds, tractor units running on biodiesel-diesel blends and multi-component fuels were field tested (including transient engine performance data, wheel slippage, etc. [87,88,103,104]) by the scientists of the Institute of Agricultural Engineering LUA during 2003–2005.

From the very beginning in 2000, transportation biofuel-related R&D efforts in Lithuania have focused on (1) the preparation of national biodiesel introduction recommendations by acting in a coordinated way at the EU level, (2) the research into physicochemical properties and exploitation characteristics of traditional food/fodder crops-based biofuels and their blends intended to be used in internal combustion engines, in order to reduce the medium- and long-term dependence on fossil fuels. Also new crops became interesting for advanced biofuels [89]. Leading Lithuanian universities and institutes were involved in EU-funded collaborative research (Table 10), some on a large scale.

Currently, R&D activity in the biofuel sector concentrates on the broad areas of biotechnology engineering [107–110] and environmental studies looking into issues concerning the development of

Table 12
Cultivation of dedicated energy crops for biofuel production [113].

Harvest of agricultural crops	2007	2008	2009	2010
Rapeseed, thous. tonnes	200	320	280 (total harvest of rapeseed 415.2)	250 (total harvest of rapeseed 475)
Triticale, thous. tonnes	60	85	135 (total harvest of triticale 245)	65 (total harvest of triticale 222)

Table 13
Share of dedicated energy crops in total area of agricultural land [113].

Agricultural crops	2010		2011	
	Thous. ha	% of total agricultural land	Thous. ha	% of total agricultural land
Rapeseed	144 (total crop area 252)	4.5	125 (total crop area 253)	4.0
Triticale	46 (total crop area 108)	1.5	21 (total crop area 97)	0.7
Total	190	6.0	146	4.7

combustible liquid fuels derived from renewable raw materials using biotechnological methods, and the identification of possible ways of increasing transesterification yields. In the few past years industrial (white) biotechnology became a rapidly growing sector of LT economy. Communication between business, science and the state is led by the Lithuanian Biotechnology Association, which was established in 1995. In 2006, the establishment of the LT National Biotechnology Platform (LNBP) enhanced these collaborations. There are a number of universities and research institutes focusing on specific objectives using modern biotechnological investigations related to industrial biotechnology and bioprocessing: Kaunas University of Technology, Vilnius Gediminas Technical University, Institute of Biochemistry at Vilnius University, Institute of Biotechnology at Vilnius University, Aleksandras Stulginskis University, Lithuanian Institute of Horticulture, Lithuanian Institute of Agriculture, Lithuanian Institute of Chemistry, and others.

4.3. Future demand for transport biofuels

Currently, two national studies have been developed on renewable energy development in LT [111]. They are: a study on energy production from renewable energy resources in 2008–2025 (Lithuanian Energy Institute, 2007) [112], and Lithuanian renewable energy promotion action plan for the period 2010–2020 [113]. In both documents, the expansion of biodiesel, bioethanol and bio-ETBE use in LT transport sector over the projection period until 2025 (see Table 11) is calculated by taking into account the policy support and other factors that impact use and tax relief for producers and consumers as well as by evaluating the mean annual increases in the number of vehicles.

Driven by policy support and renewable energy goals around the European Union, local biodiesel, bioethanol and bio-ETBE productions are projected to continue their rapid increases over the projection period and to reach respectively some 159.85 ktoe/yr. (185.87 thous. tonnes/yr.), 27.4 ktoe/yr. (42.81 thous. tonnes/yr.) and 142.7 ktoe/yr. (177.71 thous. tonnes/yr.) by 2025.

To date, liquid biofuels in LT have mostly been produced from food crops (see Tables 12 and 13) by utilizing their oil or fermentable starch content. Biodiesel and bioethanol made from vegetable oil and grains are often referred to as “1G” or “current generation” biofuels in contrast to future options (“advanced biofuels” or “2G” biofuels). The use of non-food crops is being developed, although the current use of the raw materials for biodiesel production (linseed, *Camelina sativa*, crambe, rapeseed containing high amounts of the toxic erucic acid and glucosinolates, etc.) is very small [89].

According to the most recent statistics (for the 2010 calendar year) [13] on dedicated energy crops (Tables 12 and 13), domestic biofuel production should increase to keep pace with demand. Experts in their field (Ministry of Agriculture [59], LITBIOMA) agree that, in order to help meet the 2010 interim target of 5.75% share of biofuels (energy content), it would be sufficient to increase the irrigated agricultural land area to 8% (280 thous. ha). On the other hand, in 2010, liquid biofuels production was significantly below expectations in most developing countries having implemented mandates or ambitious targets for the use of biofuels [114].

A large range of suitable compounds can, in principle, be produced from the different matters of biological origin. Nevertheless, market expansion strategy and further economic growth require commercialization of the advanced technologies. Since conventional biofuel processes, though already commercially available, continue to improve in efficiency and economics (in the case of JSC “Mestilla”), the advanced conversion routes currently are at early and late stages of the research and development. Examples of advanced technologies include, but are not limited to, the following: hybrid technologies of syngas production; synthetic fuels for diesel engines (Fischer–Tropsch biodiesel, bio-DME (Di-Methyl-Ether), biomethanol); Koch biodiesel production from organic waste; biodiesel from algae; hydrogen production processes from biomass; conversion of cellulose containing biomass into alcohols, etc.

Another future option for LT to hasten manufacture of biofuels from biomass is the development of sustainable biorefineries, including the establishment of the necessary infrastructure. Biorefineries will contribute significantly to the sustainable and efficient use of biomass resources, by providing a variety of products to different markets and sectors (co-location, smaller scale). This concept also has the potential to reduce conflicts and competition over agricultural land and plant-based feedstocks [6] as well as to integrate the various industrial and scientific communities with the expectation to achieve a breakthrough beyond the “business-as-usual” trend.

5. Conclusions

Climate change and growing Greenhouse Gas emissions are wildly discussed issues nowadays. The EU directive establishes a target of a 20% share of RES in energy consumption and a 10% target for biofuels in transport by the year 2020. Using biomass to generate energy is seen as a way to reduce GHG emissions and this has become, in recent years, the strongest driver for the introduction of transport biofuels.

During economic recession that occurred during the transition period (1990–1995), GHG emission in Lithuania decreased drastically. However, nowadays CO_2 emission is growing recently in LT and this growth could be attributed to almost all transport subsectors. The study found that the main problem with Lithuanian environmental protection legislation is the patchy nature of the regulation (there is no governmental decision indicated on the

setting up of a national fuel economy/GHG standard), from which most other problems arise.

The potential for biofuels production (biodiesel, bioethanol, bio-ETBE) in LT is investigated in relation to sustainability targets. Aspects taken into account for this analysis include food security and agricultural land availability, environmental and socio-economic aspects as well as introduction of advanced technologies. Though the country has 146–190 thous. ha of dedicated energy crops plantations (2010–2011), the untapped potential is still high. In order to help meet the 2010 interim target of 5.75% share of biofuels (energy content), it would be sufficient to increase the irrigated agricultural land area to 8% (280 thous. ha). The increase in the prices of oil and, naturally, oil products mean that many forms of bioenergy production technologies will be commercial in LT, particularly for the production of liquid biofuels.

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